US006985320B2

(12) **United States Patent**
Blaum et al.

(10) **Patent No.: US 6,985,320 B2**
(45) **Date of Patent: Jan. 10, 2006**

(54) **METHOD AND APPARATUS FOR ENCODING DATA TO GUARANTEE ISOLATED TRANSITIONS IN A MAGNETIC RECORDING SYSTEM**

(75) Inventors: **Mario Blaum**, San Jose, CA (US); **Glen Alan Jaquette**, Tucson, AZ (US); **Brian Harry Marcus**, Los Altos, CA (US); **Constantin Michael Melas**, Los Gatos, CA (US)

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 380 days.

(21) Appl. No.: **10/037,753**

(22) Filed: **Jan. 2, 2002**

(65) **Prior Publication Data**

US 2003/0123173 A1 Jul. 3, 2003

(51) **Int. Cl.**
G11B 5/09 (2006.01)

(52) **U.S. Cl.** **360/48**; 360/41; 360/51; 360/49; 360/32; 375/266; 341/95; 341/59

(58) **Field of Classification Search** 360/48, 360/39–40, 49, 41–44; 375/340–341, 355, 375/263, 266; 341/102, 106, 57–59, 81, 341/95; 714/786, 789, 796, 798
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,173,694 A * 12/1992 Lynch et al. 341/59
5,291,499 A 3/1994 Behrens et al.
5,341,387 A 8/1994 Nguyen
5,521,945 A 5/1996 Knudson
5,635,933 A 6/1997 Fitzpatrick et al.
5,661,760 A 8/1997 Patapoutian et al.
5,757,294 A 5/1998 Fisher et al.
5,757,822 A 5/1998 Fisher et al.
5,838,738 A 11/1998 Zook
5,844,507 A 12/1998 Zook
5,999,110 A * 12/1999 Blaum et al. 341/59
6,018,304 A 1/2000 Bessios
6,021,011 A 2/2000 Behrens et al.
6,032,284 A 2/2000 Bliss
6,046,691 A 4/2000 Aziz et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0751522 1/1997

(Continued)

OTHER PUBLICATIONS

McLaughlin et al, "Codes for Improved Timing Recovery in PR$ and EPR4 Magnetic Recording", Nov. 3-8, 1997, IEEE Global Telecommunications Conference, vol.: 3, pp.: 1235-1239.*

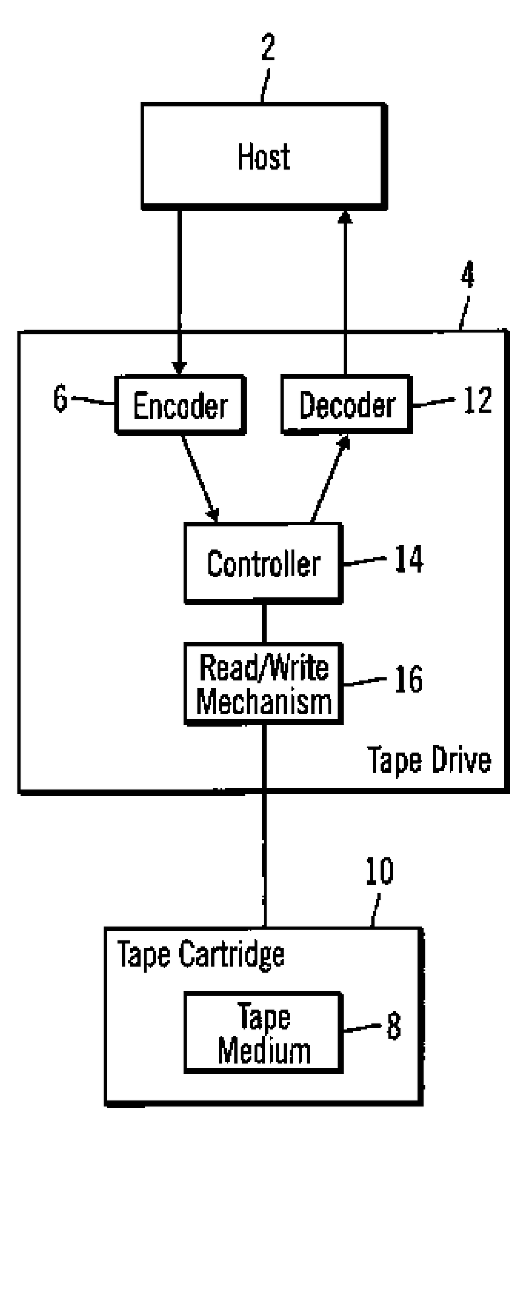
(Continued)

Primary Examiner—David Hudspeth
Assistant Examiner—Natalia Figueroa
(74) *Attorney, Agent, or Firm*—David W. Victor; Konrad Raynes & Victor LLP

(57) **ABSTRACT**

Provided is a method, system, and program for storing input groups of uncoded binary data on a storage medium. A plurality of uncoded data blocks in a data stream are received. An encoded data stream is obtained from concatenating successive encoded blocks such that the encoded data stream includes a predetermined bit pattern comprising a plurality of bits. The bit pattern always occurs within a first number of bits and two occurrences of a "1" or "0" occur within a second number of bits. The encoded data blocks are stored on the storage medium.

59 Claims, 7 Drawing Sheets



U.S. PATENT DOCUMENTS

6,072,410	A	6/2000	Kim	
6,097,320	A	8/2000	Kuki et al.	
6,097,321	A	8/2000	Sayiner	
6,115,198	A *	9/2000	Reed et al.	360/46
6,119,265	A	9/2000	Hara	
6,130,629	A	10/2000	Aziz et al.	
6,150,964	A	11/2000	McLaughin	
6,157,325	A	12/2000	Kahlman et al.	
6,184,806	B1	2/2001	Patapoutian et al.	
6,185,175	B1	2/2001	Zook	
6,246,346	B1 *	6/2001	Cloke et al.	341/59
6,429,986	B1 *	8/2002	Blaum et al.	360/41
6,643,814	B1 *	11/2003	Cideciyan et al.	714/755

FOREIGN PATENT DOCUMENTS

EP	0764950	3/1997
JP	10027433	1/1998
WO	9418670	8/1994
WO	9708836	3/1997
WO	9716011	5/1997

OTHER PUBLICATIONS

McPheters et al, "Turbo Codes for PR$ and EPR4 Magnetic Recording", Nov. 1-4, 1998, IEEE Conference Record of the Thirty-Second Asilomar Conference on Signals, Systems & Computers, vol.: 2, pp.: 1778-1782.*

Fredrickson, L. "Synchronization Sequence Detection Using a Modified Trellis Code Viterbi Detector", *IBM Technical Disclosure Bulletin*. vol. 38, No. 6, Jun. 1995. pp. 145-150.

McLaughlin, S. W., P. Lee, and R. Cloke. "Codes for Improved Timing Recovery in *PR4* and *EPR4* Magnetic Recording", *GLOBECOM 97. IEEE Global Telecommunications Conference*. vol. 3, 1997. p. 1235-9. (Abs.).

McLaughlin, Steven W., Patrick Lee, Robert Cloke, & Bane V. Basic. "One-Pairs Codes for Partial Response Magnetic Recording". *IEEE Transactions on Magnetics*, vol. 35, No. 3, May 1999. pp. 2080-2086.

U.S. Appl. No. 10/038,163, filed Jan. 2, 2002, entitled "Method, System, and Program for Synchronization and Resychronization of a Data Stream", inventor by M. Blaum, G.A. Jaquette, B.H. Marcus, and C.M. Melas.

* cited by examiner

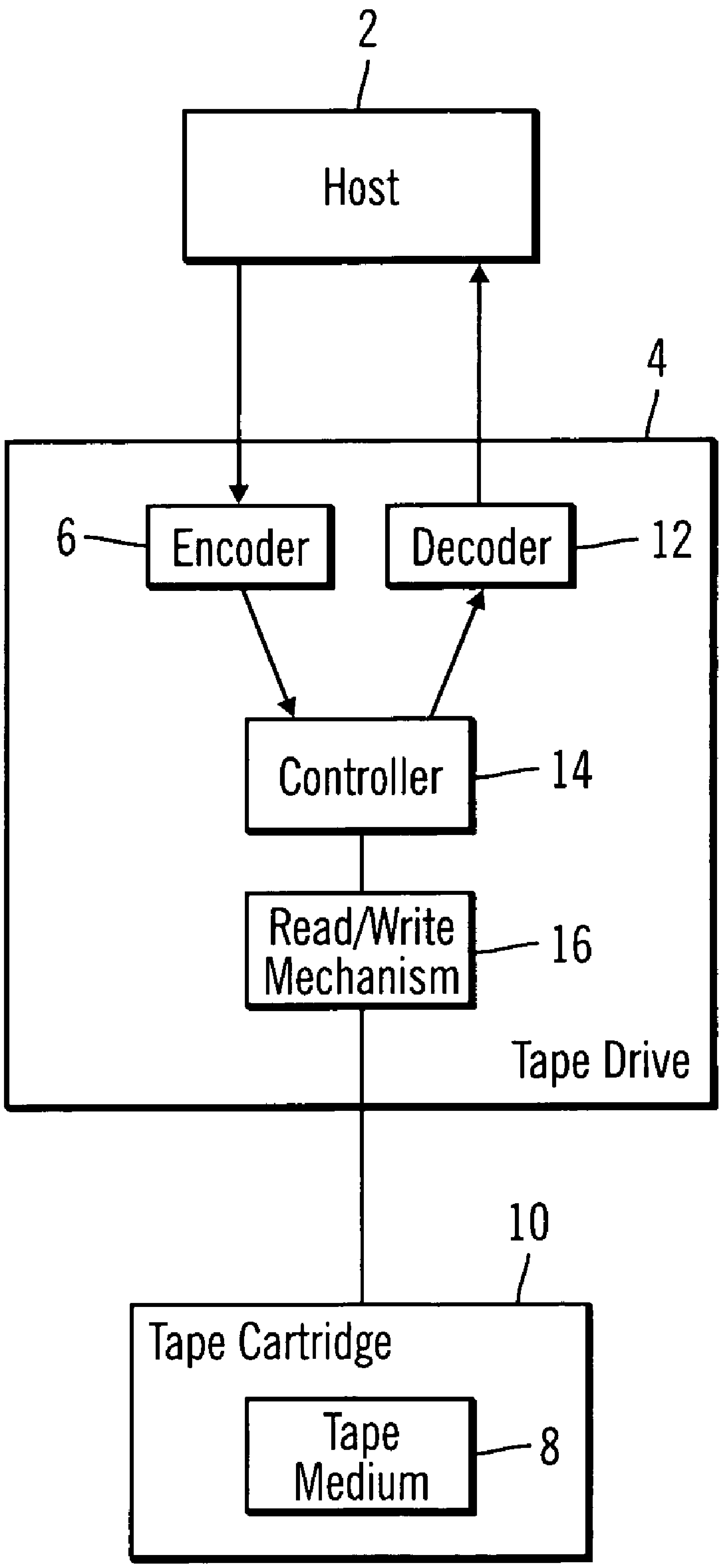

2
Host
4
6
Encoder
Decoder
12
Controller
14
Read/Write
Mechanism
16
Tape Drive
10
Tape Cartridge
Tape
Medium
8

FIG. 1

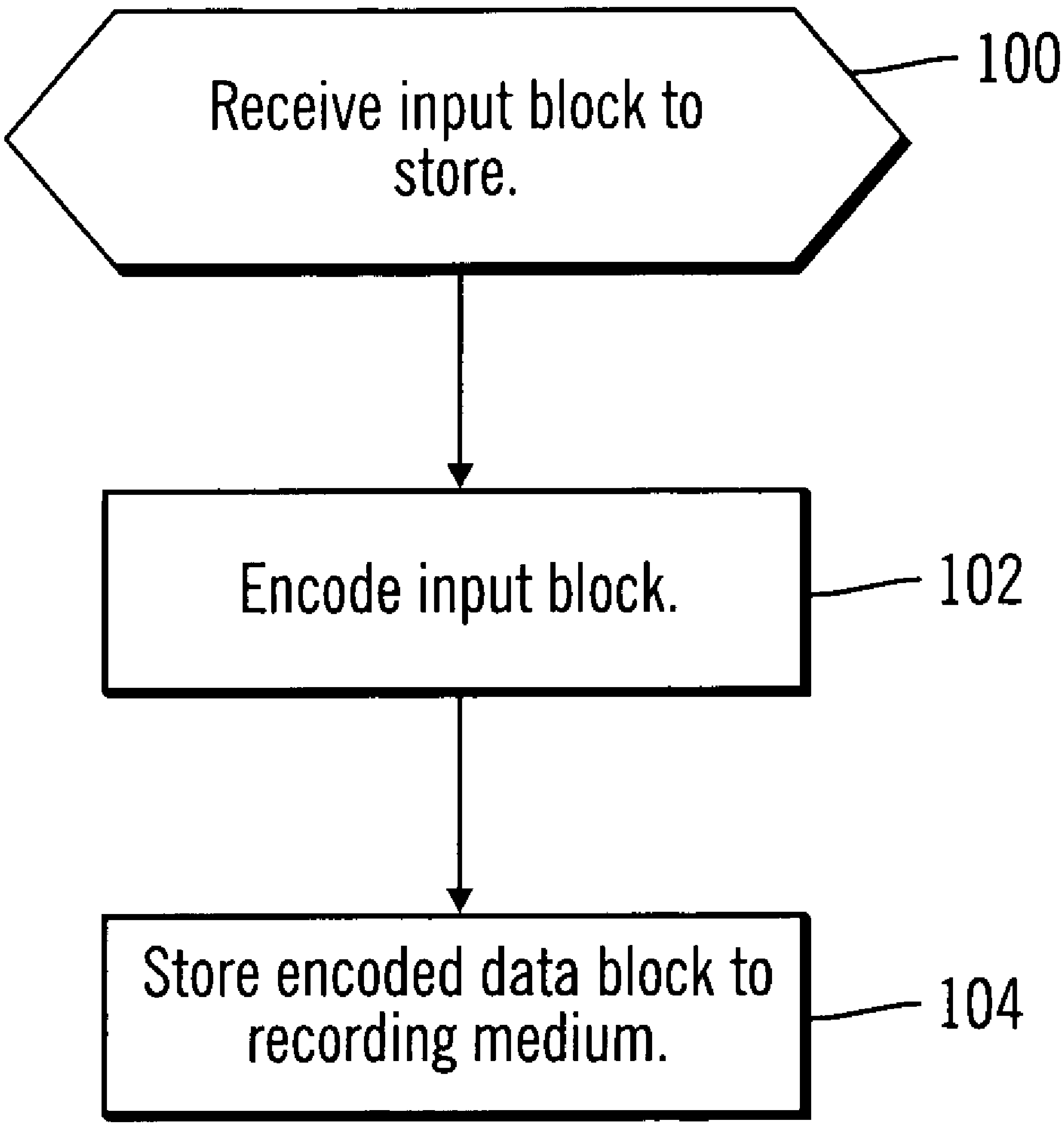

Receive input block to store.
100
Encode input block.
102
Store encoded data block to recording medium.
104

FIG. 2

FIG. 3

Modulation Code 300

Uncoded Blocks 310	Encoded Blocks 320	Uncoded Blocks 310	Encoded Blocks 320	Uncoded Blocks 310	Encoded Blocks 320
00000000	100000010	00101100	100101100	01011000	110110100
00000001	010000001	00101101	100101101	01011001	110110101
00000010	010001110	00101110	110100010	01011010	100111010
00000011	110000010	00101111	110100011	01011011	101111010
00000100	000100001	00110000	110101100	01011100	100001000
00000101	000101110	00110001	110101101	01011101	100001001
00000110	010100001	00110010	001000010	01011110	100001010
00000111	100100001	00110011	001000011	01011111	100001011
00001000	100101110	00110100	001001100	01100000	010000100
00001001	110100001	00110101	001001101	01100001	010000101
00001010	110101110	00110110	101000010	01100010	010000110
00001011	001000001	00110111	101000011	01100011	010000111
00001100	001001110	00111000	101001100	01100100	010001000
00001101	101000001	00111001	101001101	01100101	010001001
00001110	101001110	00111010	001100010	01100110	010001010
00001111	111000010	00111011	101100010	01100111	010001011
00010000	001010001	00111100	011000010	01101000	110001000
00010001	100010001	00111101	011100010	01101001	110001001
00010010	100011010	00111110	111000100	01101010	110001010
00010011	010011110	00111111	111000101	01101011	110001011
00010100	110011010	01000000	001010010	01101100	000100100
00010101	010111110	01000001	001010011	01101101	000100101
00010110	011110010	01000010	100010100	01101110	000100110
00010111	011111010	01000011	100010101	01101111	000100111
00011000	110110010	01000100	101010001	01110000	000101000
00011001	110111010	01000101	101010100	01110001	000101001
00011010	100000100	01000110	010011100	01110010	000101010
00011011	100000101	01000111	010011101	01110011	000101011
00011100	010000010	01001000	001011110	01110100	010100100
00011101	010000011	01001001	101011110	01110101	010100101
00011110	010001100	01001010	011011010	01110110	010100110
00011111	010001101	01001011	111011010	01110111	010100111
00100000	110000100	01001100	000110010	01111000	010101000
00100001	110000101	01001101	001110010	01111001	010101001
00100010	000100010	01001110	000111010	01111010	010101100
00100011	000100011	01001111	001111010	01111011	010101101
00100100	000101100	01010000	010110010	01111100	100100100
00100101	000101101	01010001	010110011	01111101	100100101
00100110	010100010	01010010	010111100	01111110	100100110
00100111	010100011	01010011	010111101	01111111	100100111
00101000	010101011	01010100	011110100	10000000	100101000
00101001	010101110	01010101	011110101	10000001	100101001
00101010	100100010	01010110	100110010	10000010	100101010
00101011	100100011	01010111	101110010	10000011	100101011

FIG. 3 (con't)

Modulation Code 300 (con't)

Uncoded Blocks 310	Encoded Blocks 320	Uncoded Blocks 310	Encoded Blocks 320	Uncoded Blocks 310	Encoded Blocks 320
10000100	110100100	10110000	010011000	11011100	100010110
10000101	110100101	10110001	010011001	11011101	100010111
10000110	110100110	10110010	010011010	11011110	101010110
10000111	110100111	10110011	010011011	11011111	101010111
10001000	110101000	10110100	001011100	11100000	010010010
10001001	110101001	10110101	001011101	11100001	010010011
10001010	110101010	10110110	101011100	11100010	011010010
10001011	110101011	10110111	101011101	11100011	011010011
10001100	001000100	10111000	000110100	11100100	110010010
10001101	001000101	10111001	000110101	11100101	110010011
10001110	001000110	10111010	001110100	11100110	111010010
10001111	001000111	10111011	001110101	11100111	111010011
10010000	001001000	10111100	010110100	11101000	001011000
10010001	001001001	10111101	010110101	11101001	001011001
10010010	001001010	10111110	010110110	11101010	001011010
10010011	001001011	10111111	010110111	11101011	001011011
10010100	101000100	11000000	010111000	11101100	101011000
10010101	101000101	11000001	010111001	11101101	101011001
10010110	101000110	11000010	010111010	11101110	101011010
10010111	101000111	11000011	010111011	11101111	101011011
10011000	101001000	11000100	100110100	11110000	010010100
10011001	101001001	11000101	100110101	11110001	010010101
10011010	101001010	11000110	101110100	11110010	010010110
10011011	101001011	11000111	101110101	11110011	010010111
10011100	001100100	11001000	001101000	11110100	110010100
10011101	001100101	11001001	001101001	11110101	110010101
10011110	101100100	11001010	001101010	11110110	110010110
10011111	101100101	11001011	001101011	11110111	110010111
10100000	111001000	11001100	101101000	11111000	011010100
10100001	111001001	11001101	101101001	11111001	011010101
10100010	111001010	11001110	101101010	11111010	011010110
10100011	111001011	11001111	101101011	11111011	011010111
10100100	011000100	11010000	011001000	11111100	111010100
10100101	011000101	11010001	011001001	11111101	111010101
10100110	011100100	11010010	011001010	11111110	111010110
10100111	011100101	11010011	011001011	11111111	111010111
10101000	001010100	11010100	011101000		
10101001	001010101	11010101	011101001		
10101010	001010110	11010110	011101010		
10101011	001010111	11010111	011101011		
10101100	010010001	11011000	100010010		
10101101	110010001	11011001	100010011		
10101110	011010001	11011010	101010010		
10101111	111010001	11011011	101010011		

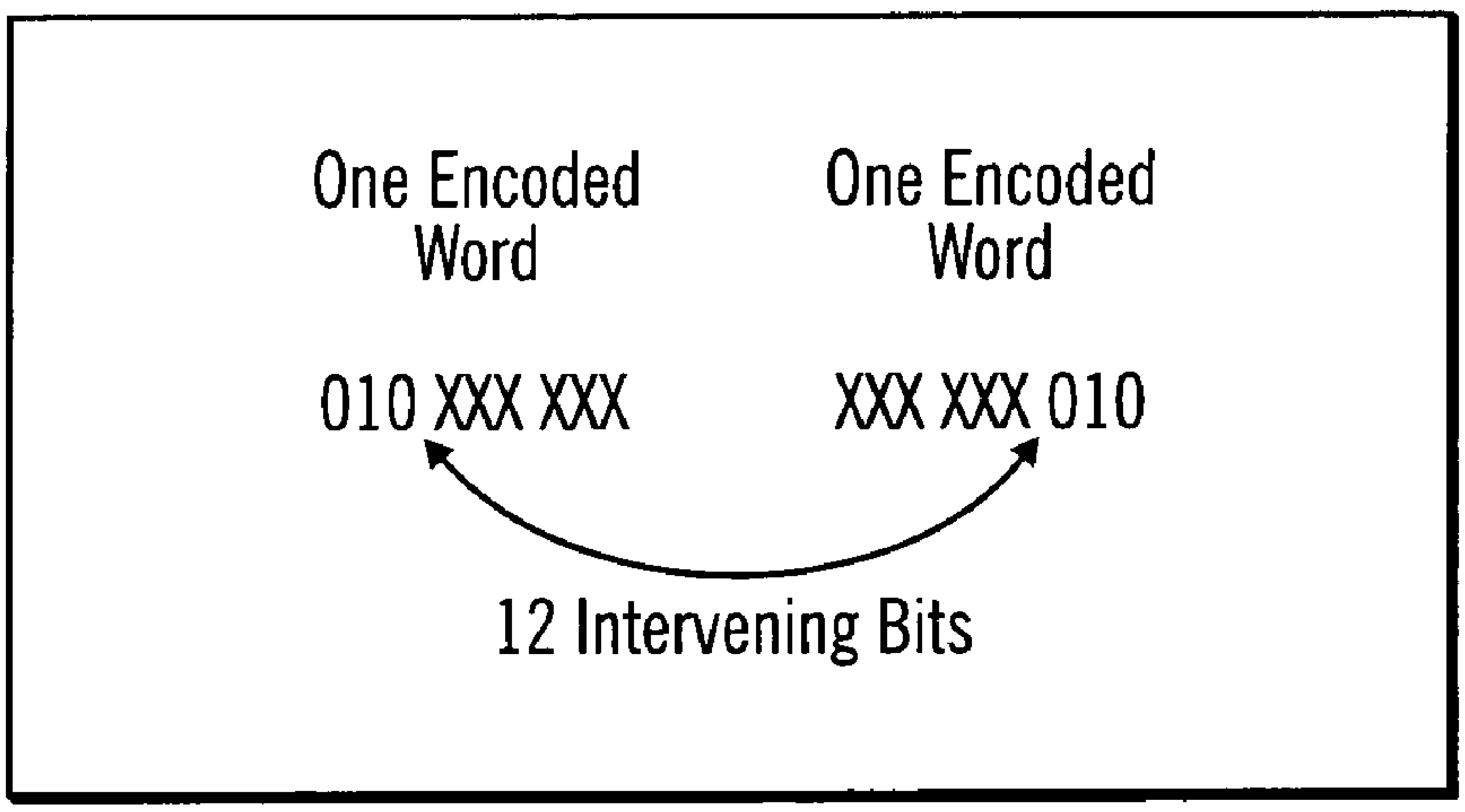

One Encoded Word
One Encoded Word
010 XXX XXX
XXX XXX 010
12 Intervening Bits

FIG. 4

Modulation Code 500*

Unencoded Blocks 510										Encoded Blocks 520									
0	0	a_2	a_3	a_4	a_5	a_6	a_7	a_8	↔	1	1	1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
0	1	0	a_3	a_4	a_5	a_6	a_7	a_8	↔	0	1	1	1	a_3	a_4	a_5	a_6	a_7	a_8
0	1	1	a_3	a_4	a_5	a_6	a_7	a_8	↔	a_3	0	1	1	1	a_4	a_5	a_6	a_7	a_8
1	0	0	a_3	a_4	a_5	a_6	a_7	a_8	↔	a_3	a_4	0	1	1	1	a_5	a_6	a_7	a_8
1	0	1	0	a_4	a_5	a_6	a_7	a_8	↔	a_5	a_4	0	0	1	1	1	a_6	a_7	a_8
1	0	1	1	0	a_5	a_6	a_7	a_8	↔	a_5	0	1	0	1	1	1	a_6	a_7	a_8
1	0	1	1	1	0	a_6	a_7	a_8	↔	0	1	1	0	1	1	1	a_6	a_7	a_8
1	a_5	a_5	1	a_5	a_5	a_6	a_7	a_8	↔	a_5	0	1	a_6	0	1	1	1	a_7	a_8
1	1	0	0	a_4	a_5	a_6	a_7	a_8	↔	a_5	a_4	1	a_6	0	1	1	1	a_7	a_8
1	1	0	1	0	1	0	a_7	a_8	↔	0	1	1	0	0	1	1	1	a_7	a_8
1	1	1	0	a_4	a_5	a_6	a_7	a_8	↔	a_4	a_5	0	a_6	a_7	0	1	1	1	a_8
1	1	1	1	0	0	a_6	a_7	a_8	↔	a_6	0	1	0	a_7	0	1	1	1	a_8
1	1	0	1	0	1	1	a_7	a_8	↔	a_7	0	1	1	0	0	1	1	1	a_8
1	1	0	1	1	0	0	a_7	a_8	↔	0	1	1	0	a_7	0	1	1	1	a_8
1	1	1	1	a_5	a_5	a_6	a_7	a_8	↔	a_5	0	a_6	a_7	0	a_8	0	1	1	1
1	1	0	1	1	0	1	a_7	a_8	↔	a_7	1	0	0	1	a_8	0	1	1	1
1	1	0	1	1	1	a_6	a_7	a_8	↔	a_6	0	a_7	0	1	a_8	0	1	1	1
1	1	1	1	1	1	a_6	a_7	a_8	↔	a_6	1	0	a_7	0	a_8	0	1	1	1

*The above modulation code 500 may be used, in certain implementations, for all 9 bit unencoded blocks except for the block "001111111", which in certain cases encodes instead to the 10 bit block "0110000111".

FIG. 5

Modulation Code 600

Unencoded Sequences 610										Encoded Sequences 620									
0	0	a_2	a_3	a_4	a_5	a_6	a_7	a_8	--	0	a_2	a_2	0	a_3	a_4	a_5	a_6	a_7	a_8
0	1	0	0	a_4	a_5	a_6	a_7	a_8	--	1	0	1	0	0	a_4	a_5	a_6	a_7	a_8
0	1	1	a_3	a_4	a_5	a_6	a_7	a_8	--	a_3	0	0	1	0	a_4	a_5	a_6	a_7	a_8
a_3	a_3	0	a_3	a_4	a_5	a_6	a_7	a_8	--	a_3	a_4	0	a_4	a_4	0	a_5	a_6	a_7	a_8
1	0	0	1	0	a_5	a_6	a_7	a_8	--	1	a_5	a_5	0	1	0	a_5	a_6	a_7	a_8
1	0	0	1	1	a_5	a_6	a_7	a_8	--	a_5	1	1	0	1	0	0	a_6	a_7	a_8
1	0	1	0	a_4	a_5	a_6	a_7	a_8	--	a_4	a_5	a_5	0	0	1	0	a_6	a_7	a_8
1	0	1	1	0	0	a_6	a_7	a_8	--	1	1	0	0	0	1	0	a_6	a_7	a_8
1	0	1	1	1	1	a_6	a_7	a_8	--	a_6	1	0	1	0	1	0	0	a_7	a_8
1	a_3	a_3	a_3	1	a_5	a_6	a_7	a_8	--	a_3	a_5	1	1	0	a_6	a_6	0	a_7	a_8
1	a_5	a_5	a_5	0	a_5	a_6	a_7	a_8	--	a_5	a_6	0	a_6	0	a_6	a_6	0	a_7	a_8
1	1	0	0	0	1	a_6	a_7	a_8	--	a_6	1	1	0	0	0	1	0	a_7	a_8
1	1	0	1	0	a_5	a_6	a_7	a_8	--	a_5	a_6	a_7	1	1	0	1	0	0	a_8
1	1	0	1	1	0	0	a_7	a_8	--	a_7	1	1	0	1	0	1	0	0	a_8
1	1	0	1	1	0	1	a_7	a_8	--	1	a_7	a_7	0	1	0	1	0	0	a_8
1	1	0	1	1	a_5	a_6	a_7	a_8	--	a_5	a_6	1	1	a_7	0	0	1	0	a_8
1	1	0	1	a_6	1	a_6	a_7	a_8	--	a_6	a_7	a_7	0	0	0	0	1	0	a_8
1	1	1	0	0	0	a_6	a_7	a_8	--	a_6	a_7	0	1	1	0	0	1	0	a_8
1	1	1	0	0	1	a_6	a_7	a_8	--	a_6	a_7	a_8	1	1	1	0	1	0	0
1	1	1	0	1	0	a_6	a_7	a_8	--	a_6	a_7	1	1	a_8	1	0	1	0	0
1	1	1	0	1	1	0	a_7	a_8	--	1	a_7	a_8	0	1	1	0	1	0	0
1	1	1	1	1	a_5	a_6	a_7	a_8	--	a_5	a_6	a_7	1	1	a_8	0	0	1	0
1	1	1	0	1	1	1	a_7	a_8	--	a_7	a_8	1	1	0	0	0	0	1	0

FIG. 6

METHOD AND APPARATUS FOR ENCODING DATA TO GUARANTEE ISOLATED TRANSITIONS IN A MAGNETIC RECORDING SYSTEM

RELATED APPLICATIONS

This application is related to the copending and commonly assigned U.S. patent application entitled "Method, System, and Program for Synchronization and Resynchronization of a Data Stream", having Ser. No. 10/038,163, which patent application was filed on the same date herewith and is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and apparatus for storing data in a storage medium. More specifically, the present invention relates to gain and timing control in storing data in a storage medium.

2. Description of the Related Art

In data recording systems, a data drive writes positive and negative "flux transitions" to the medium. A "one" bit ("1") represents a peak or trough in the signal while a "zero" bit ("0") indicates that no signal is present. These flux transitions within a data stream can be used to provide feedback for timing and gain control loops. However, if a string of zeros exist for too long, a phase change may not be detected, causing errors in the recording system. This problem can be avoided if the data is encoded so that a "1" is guaranteed to occur at a definite minimum frequency. This is the purpose of modulation coding subject to a classical runlength limited k-constraint.

But there may be advantages to using timing marks or gain control marks other than the symbol "1." In the 1999 publication "One-Pairs Codes for Partial Response Magnetic Recording," IEEE Transactions on Magnetics, Vol. 35, No. 3, May 1999, the use of a pair of 1s (i.e. "11") is described to perform timing recovery for readback of information stored on magnetic recording media in a partial response channel. Still other channel models may benefit from a different encoding system to provide additional features, but the systems are limited to the available control marks and coding blocks in the prior art.

Thus, there is a need in the art to provide more sophisticated timing and gain control marks and/or improved coding algorithms for encoding and storing data in a storage medium.

SUMMARY OF THE PREFERRED EMBODIMENTS

Provided is a method, system, and program for storing input groups of uncoded binary data on a storage medium. A plurality of uncoded data blocks in a data stream are received. An encoded data stream is obtained from concatenating successive encoded blocks such that the encoded data stream includes a predetermined bit pattern comprising a plurality of bits. The bit pattern always occurs within a first number of bits and two occurrences of a "1" or "0" occur within a second number of bits. The encoded data stream is stored on the storage medium.

In further implementations, the predetermined bit pattern comprises "010". In such case, each uncoded data block may comprise eight bits and each encoded data block may comprise nine bits. Still further, each uncoded data block may comprise sixteen bits and each encoded data block may comprise seventeen bits.

In still further implementations, the predetermined bit pattern may comprise "111". In such case, each uncoded data block comprises nine bits and each encoded data block comprises ten bits.

Still further, the predetermined bit pattern may comprise either "0100" or "0010". In such case, each uncoded data block comprises sixteen bits, each encoded data block comprises seventeen bits, and the first number comprises fifteen bits.

In further implementations, the predetermined bit pattern comprises 111 and the m/n rate coded block comprises a 9/10 rate coded block. In still further implementation, the predetermined bit pattern comprises either 0010 or 0100, and the m/n rate coded block comprises a 9/10 rate coded block.

The described implementations provide a technique to encode uncoded binary data at a guaranteed minimum frequency rate using predetermined binary patterns representing peaks in an analog waveform which can provide improved timing and gain control.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1** illustrates a storage environment in which aspects of the invention are implemented;

FIG. **2** illustrates a data flow implemented in the encoder to encode and store a block of uncoded binary user data in accordance with implementations of the invention;

FIG. **3** illustrates an encoding table using a "001" binary pattern in accordance with implementations of the invention;

FIG. **4** illustrates the maximum separation between consecutive peaks embodied by the "010" binary pattern in accordance with implementations of the invention;

FIG. **5** illustrates an encoding table using a "111" binary pattern in accordance with implementations of the invention; and

FIG. **6** illustrates an encoding table using a "0100" or "0010" binary patterns in accordance with implementations of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description, reference is made to the accompanying drawings which form a part hereof and which illustrate several embodiments of the present invention. It is understood that other embodiments may be utilized and structural and operational changes may be made without departing from the scope of the present invention.

FIG. **1** illustrates a tape storage environment in which aspects of the invention are implemented. A host system **2** is in communication with a tape drive **4**. The tape drive **4** may be a component within the host system **2** enclosure or a drive within a tape library or tape server that the host system **2** communicates with over a network (not shown). The tape drive **4** includes an encoder **6** to encode data received from the host **2** that is to be written on tape medium **8** in a tape cartridge **10** engaged with the tape drive **4**. The tape drive **4** further includes a decoder **12** to decode data stored on the tape medium **8** to return to the host system **2**. A controller **14** within the tape drive **4** drives a read/write mechanism **16** to perform read and write operations with respect to encoded data on the tape medium **8** in a manner known in the art. The encoder **6** and decoder **12** may be implemented as separate hardware components external to the controller **14** or implemented within logic executed by the controller **14**.

In alternative implementations, the tape drive **4** may comprise other types of storage devices, such as a hard disk drive, optical disk or other device for reading and writing data to a non-volatile storage medium. In the described implementations, the tape medium **8** comprises a magnetic or digital tape.

FIG. **2** illustrates the data flow implemented in the encoder **6** to encode and store a block of uncoded binary user data in accordance with one implementation of the invention. Control begins at block **100** when the encoder **6** receives a block of binary user data for storage on the medium **100**. Next, at block **102**, the encoder encodes the block of binary user data in preparation for storage on the tape medium **8**. Specifically, the encoder **6** encodes each word of the binary data block using an "m/n rate code block." Under this coding scheme, which is shown in FIG. **3**, "m" represents the number of bits in a "group" of uncoded binary user bits **310** to be encoded, and the "n" represents the number of bits in the corresponding "group" of encoded bits **320**. Each group of "n" encoded bits **320** contains at least one binary pattern that enables improved reliability of gain and timing control operations, as discussed below in more detail. After the encoder **6** individually encodes groups of uncoded binary user data **310**, the encoded data **320** is stored on the tape medium **8** at block **104**. More particularly, the read/write mechanism **16** stores binary flux transitions corresponding to the encoded binary bit block to the recording medium **100**. The storing of the data can be performed using known techniques in the art.

FIG. **3** illustrates a modulation code table **300** implemented in the encoder **6** and decoder **12** to respectively encode and decode data. The modulation code table **300** provides a high rate modulation to encode the arbitrary binary data blocks **310** into encoded blocks **320** at an 8/9 code rate (i.e. a "group" of uncoded bits includes 8 bits and a "group" of encoded bits includes 9 bits). More specifically, a "group" of uncoded binary user data occupies 8 bits, encompassing all possible input combinations from "00000000" to "11111111." Each "group" of encoded bits occupies nine bits, and contains at least one predetermined binary pattern, also referred to as "timing (or gain) control marks" or simply "marks." In the implementation of FIG. **3**, the predetermined binary pattern "010" is used, which represents an isolated peak in an analog readback waveform. For extended partial response channels, the pattern "010" provides much greater reliability than simply a "1" in the classical k-constraint or "11" described in the IEEE publication "One-Pairs Codes for Partial Response Magnetic Recording."

In the implementation of FIG. **3**, the predetermined pattern "010" is guaranteed to occur within each encoded data block **320** such that the binary patterns (i.e. "010") from two neighboring encoded groups cannot be separated by more than 12 intervening bits in a traditional PR4 ("Partial Response") system, as shown by FIG. **4**. Further, with the modulation pattern of FIG. **3**, the maximum gap between two occurrences of"1" and two occurrences of "0" is 6 bits, as can be shown by examining FIG. **3**. Accordingly, the "010" pattern occurs in the encoded bit stream with a guaranteed number of bits and any two occurrences of "1" and two occurrences of "0" occur within a number of bits less that is less than the maximum number of bits between the "010" pattern. This ensures that a maximum possible amplitude occurs between instances of the predetermined number of bits, i.e., predetermined frequency, in a manner that isolates peaks and aid in analog gain control and digital timing recovery. Also, because the maximum gap between two occurrences of"1" and two occurrences of "0" is 6 bits, this code satisfies a traditional PRML G constraint, which aids in traditional PR4 timing algorithms. Moreover, this code satisfies a traditional I constraint, which helps to limit the Viterbi path memory. Moreover, the code avoids an indefinite run of the VFO field (by excluding the two words (010101010 and 101010101).

In designing a code, the following goals should be considered: the ease with which the code can be decoded; the compatibility of the binary pattern with the system; occurrence at a sufficiently a high frequency, or within a relatively low predetermined number of bits; and the ability to consider noise enhancement, channel impulse response, and implementation complexity. The code described in FIG. **3** provides a high frequency rate, low complexity, and very little error propagation.

The 8/9 block codes described in FIG. **3** can readily be extended to an extended block code having a 16/17 bit code rate. By appending additional eight bits to the encoded nine bits by alternating encoded bytes with uncoded bytes, a block code using a 16/17 bit code rate is also available. With this 16/17 bit encoding scheme, the binary patterns (i.e. "010") from two neighboring encoded groups cannot be separated by more than 20 intervening bits in a traditional PR4 ("Partial Response") system, and the maximum gap between two occurrences of "1" and two occurrences of "0" is 14 bits.

The 16/17 bit code rate may be implemented as a block coded sequence or finite state code sequence. In the block coded sequence implementation, there is a one-to-one correspondence of uncoded blocks to encoded blocks. In a finite state code implementation, the same uncoded block may be represented by two different encoded blocks or one encoded block can represent two different uncoded blocks, and ambiguity is resolved by looking at adjacent blocks.

FIG. **5** illustrates an encoding table using an alternative "111" binary pattern in accordance with implementations of the invention. In the preferred implementations, a high rate modulation code **500** is used to encode the arbitrary binary data blocks **510** into encoded blocks **520** at a 9/10 code rate (i.e. a "group" of uncoded bits includes 9 bits and a "group" of encoded bits comprises 10 bits). Each subscripted "a" character refers to the value of a bit of the uncoded group **510**, where the subscript identifies the bit's position in the group **510**. For example, a_0 identifies the binary "0" or "1" located at the first bit position of the uncoded group **510**. In FIG. **5**, all possible uncoded groups **510** and the corresponding output encoded groups **520** are shown. In the PR4 system, the first and last ones must have opposite signs, on either side of a waveform peak, and two consecutive ones of opposite sign, on either side of a zero crossing. For instance, if the first one in "111" corresponds to +1, then the third one corresponds to −1. Thus, there are going to be two consecutive ones having the same sign, corresponding to a peak in PR4. The modulation code **500** ensures that the binary pattern "111" appears in each encoded data block **520**. With this encoding scheme, the binary patterns (i.e. "111") from two neighboring encoded groups cannot be separated by more than 14 intervening bits at a 9/10 bit code rate and 21 intervening bits in an extended 16/17 bit code rate. In order to obtain a 16/17 code, seven bits are added. In certain implementations, the encoding table of FIG. **5** is to be used for all nine bit unencoded blocks except for the block

"001111111", which encodes instead to the ten bit block "0110000111". This ensures that every codeword contains both a "0" and a "1" Otherwise, other factors must be used to select the uncoded to encoded block correspondence, such as the case with a finite state coding.

FIG. **6** illustrates an encoding table using an alternative "0100" or "0010" binary patterns in accordance with further implementations of the invention. In the preferred implementations, a high rate modulation code **600** is used to encode the arbitrary binary data blocks **610** into encoded blocks **620** at a 9/10 code rate (i.e. a "group" of uncoded bits includes 9 bits and a "group" of encoded bits includes 10 bits). As in FIG. **5**, each subscripted "a" character refers to the value of a bit of the uncoded group **610**, where the subscript identifies the bit's position in the group **610**. In FIG. **6**, all possible uncoded groups **610** and the corresponding output encoded groups **620** are shown. The modulation code **600** ensures that the binary pattern "0100" or "0010" appears in each encoded data block **520**. The binary patterns "0100" or "0010" are suitable for implementation in NRZI, giving peaks both in EPR4 ("Extended Partial Response") and E^2PR4 ("Extended Partial Response 2") systems. Moreover, using longer binary patterns "0100" or "0010" can increase the frequency of the timing mark in the encoded data. By using alternative timing marks within a single block code, the binary patterns (i.e. "0100" or "0010") from two neighboring encoded groups cannot be separated by more than 12 intervening bits for the 9/10 bit code rate and 19 intervening bits for the extended 16/17 bit code rate, rather than 20 intervening bits in a code block using a single timing mark.

ADDITIONAL IMPLEMENTATION DETAILS

The preferred embodiments may be implemented as a method, apparatus or article of manufacture using standard programming and/or engineering techniques to produce software, firmware, hardware, or any combination thereof. The term "article of manufacture" as used herein refers to code or logic implemented in hardware logic (e.g., an integrated circuit chip, Field Programmable Gate Array (FPGA), Application Specific Integrated Circuit (ASIC), etc.) or a computer readable medium (e.g., magnetic storage medium (e.g., hard disk drives, floppy disks, tape, etc.), optical storage (CD-ROMs, optical disks, etc.), volatile and non-volatile memory devices (e.g., EEPROMs, ROMs, PROMs, RAMs, DRAMs, SRAMs, firmware, programmable logic, etc.). Code in the computer readable medium is accessed and executed by a processor. The code in which preferred embodiments are implemented may further be accessible through a transmission media or from a file server over a network. In such cases, the article of manufacture in which the code is implemented may comprise a transmission media, such as a network transmission line, wireless transmission media, signals propagating through space, radio waves, infrared signals, etc. Of course, those skilled in the art will recognize that many modifications may be made to this configuration without departing from the scope of the present invention, and that the article of manufacture may comprise any information bearing medium known in the art.

In the described implementations, the encoding process was described with respect to encoding the uncoded binary user data into encoded data. The present invention also encompasses decoding the encoded data back to the uncoded binary user data using the same block codes because the encoders are one-to-one correspondences. Additional hardware may be used in the readback process including a decoder. More specifically, the decoder decodes the encoded bit stream by reversing the translation of FIG. **3** to effectively decode each encoded group of bits back into an uncoded 8-bit group. Similarly, the decoder can reverse the translation of FIGS. **5** and **6** to effectively decode each encoded group of bits back into an uncoded 9-bit group. For finite-state codes, certain encoded words may represent more than one possible uncoded bit group, the decoder may apply known methods (i.e. look at the next code word) to determine the correct translation.

In certain described implementations, the encoder tables provide a one-to-one correspondence of uncoded to encoded blocks. In alternative implementations, finite-state codes can be used instead of the block code using finite-state encoders. A finite-state encoder will encode each user data block into a block that satisfies the given constraint of the system at some rate m/n. Each m-bit user input is encoded into an n-bit codeword as a function of the current state (as well as the user input), wherein the state transition consists of an initial state, terminal state, m-bit input and n-bit codeword. In finite-state coding schemes, the same encoded codeword can correspond to two different uncoded user data blocks (providing such benefits as a higher frequency rate and smaller gap distance between timing marks vs. the costs of increased complexity) and one uncoded block can correspond to two encoded blocks. In finite-state codes, the state information is used to determine how to properly decode the encoded data, i.e., by using the value of adjacent blocks to determine the uncoded to coded block mapping.

The described implementations provide a technique for transferring data to a tape drive. The above described logic may be used with other input/output (I/O) devices or other storage devices, e.g., optical tape, magnetic tape, magnetic disk, etc.

The logic implementation of FIG. **2** described specific operations as occurring in a particular order. In alternative implementations, certain of the flow operations may be performed in a different order, modified or removed and still implement preferred embodiments of the present invention. Morever, steps may be added to the above described flow and still conform to implementations of the invention.

The foregoing description of the preferred embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto. The above specification, examples and data provide a complete description of the manufacture and use of the composition of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

What is claimed is:

1. A method for storing input groups of uncoded binary data on a storage medium, comprising:

receiving a plurality of uncoded data blocks in a data stream;

generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" always occur within a second number of bits; and storing the encoded data stream on the storage medium.

2. The method of claim **1**, wherein the predetermined bit pattern represents a maximum amplitude peak in a constrained waveform that is guaranteed to occur within the first number of bits.

3. The method of claim **1**, wherein the encoded data blocks are generated using an encoder table.

4. The method of claim **1**, further comprising:

decoding the encoded data block by determining the decoded data block corresponding to the encoded data block.

5. The method of claim **1**, wherein the encoding function is performed by a finite state code.

6. The method of claim **5**, wherein one encoded data block corresponds to multiple uncoded data blocks, and wherein a value of at least one adjacent block is used to determine the uncoded data block that corresponds to the encoded data block corresponding to multiple uncoded data blocks.

7. The method of claim **1**, wherein the predetermined bit pattern comprises "010", each uncoded data block comprises eight bits, and each encoded data block comprises nine bits.

8. The method of claim **7**, wherein the first number comprises twelve and the second number comprises six.

9. The method of claim **1**, wherein the predetermined bit pattern comprises "010", wherein each uncoded data block comprises sixteen bits and wherein each encoded data block comprises seventeen bits.

10. The method of claim **9**, wherein the first number comprises twenty bits and the second number comprises fourteen bits.

11. The method of claim **9**, wherein a correspondence of uncoded to encoded data blocks comprises a finite state code scheme.

12. The method of claim **1**, wherein the predetermined bit pattern comprises "111", wherein each uncoded data block comprises nine bits and wherein each encoded data block comprises ten bits.

13. The method of claim **12**, wherein the first number is fourteen.

14. The method of claim **1**, wherein the predetermined bit pattern comprises "111", wherein each uncoded data block comprises sixteen bits, and wherein each encoded data block comprises seventeen bits.

15. The method of claim **14**, wherein the first number is twenty-one.

16. The method of claim **14**, wherein a correspondence of uncoded to encoded data blocks comprises a finite state code scheme.

17. The method of claim **1**, wherein the predetermined bit pattern comprises either "0100" or "0010", wherein each uncoded data block comprises nine bits and wherein each encoded data block comprises ten bits.

18. The method of claim **17**, wherein the first number is twelve.

19. The method of claim **1**, wherein the predetermined bit pattern comprises either "0100" or "0010", wherein each uncoded data block comprises sixteen bits.

20. The method of claim **19**, wherein each encoded data block comprises seventeen bits and wherein the firm number comprises nineteen bits.

21. The method of claim **19**, wherein a correspondence of uncoded to encoded data blocks comprises a finite state code scheme and wherein the first number is fifteen.

22. The method of claim **1**, wherein the predetermined bit pattern is included in one encoded data block or spans two encoded data blocks.

23. A method for storing input groups of uncoded binary data on a storage medium, comprising:

receiving a plurality of uncoded data blocks in a data stream;

generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits, and two occurrences of a "1" and "0" occur within a second number of bits, wherein the first number is greater than the second number; and

storing the encoded data stream on the storage medium.

24. A method for storing input groups of uncoded binary data on a storage medium, comprising:

receiving a plurality of uncoded data blocks in a data stream;

generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" occur within a second number of bits; and

storing the encoded data stream on the storage medium, wherein the encoded data block can be used in partial response and extended partial response systems.

25. A system for storing input groups of uncoded binary data on a storage medium, comprising:

means for receiving a plurality of uncoded data blocks in a data stream;

means for generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" always occur within a second number of bits; and

means for storing the encoded data stream on the storage medium.

26. The system of claim **25**, wherein the predetermined bit pattern represents a maximum amplitude peak in a constrained waveform that is guaranteed to occur within the first number of bits.

27. The system of claim **25**, wherein the encoding function is performed by a finite state code.

28. The system of claim **27**, wherein one encoded data block corresponds to multiple uncoded data blocks, and wherein a value of at least one adjacent block is used to determine the uncoded data block that corresponds to the encoded data block corresponding to multiple uncoded data blocks.

29. The system of claim **25**, wherein the predetermined bit pattern comprises "010" each uncoded data block comprises eight bits, and each encoded data block comprises nine bits.

30. The system of claim **25**, wherein the predetermined bit pattern comprises "111", wherein each uncoded data block comprises nine bits and wherein each encoded data block comprises ten bits.

31. The system of claim **25**, wherein the predetermined bit pattern comprises "111", wherein each uncoded data block comprises sixteen bits, wherein each encoded data block comprises seventeen bits.

32. The system of claim **25**, wherein the predetermined bit pattern comprises either "0100" or "0010" wherein each uncoded data block comprises nine bits and wherein each encoded data block comprises ten bits.

33. The system of claim **25**, wherein the predetermined bit pattern is included in one encoded data block or spans two encoded data blocks.

34. A system for storing input groups of uncoded binary data on a storage medium, comprising:

means for receiving a plurality of uncoded data blocks in a data stream;

means for generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" occur within a second number of bits, wherein the first number is greater than the second number; and

means for storing the encoded data stream on the storage medium.

35. An article of manufacture including code for storing input groups of uncoded binary data on a storage medium, wherein the code is capable of causing operations comprising:

receiving a plurality of uncoded data blocks in a data stream;

generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from, concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" always occur within a second number of bits; and

storing the encoded data stream on the storage medium.

36. The article of manufacture of claim **35**, wherein the predetermined bit pattern represents a maximum amplitude peak in a constrained waveform that is guaranteed to occur within the first number of bits.

37. The article of manufacture of claim **35**, wherein the encoded data blocks are generated using an encoder table.

38. The article of manufacture of claim **35**, further comprising:

decoding the encoded data block by determining the decoded data block corresponding to the encoded data block.

39. The article of manufacture of claim **35**, wherein the encoding function is performed by a finite state code.

40. The article of manufacture of claim **39**, wherein one encoded data block corresponds to multiple uncoded data blocks, and wherein a value of at least one adjacent block is used to determine the uncoded data block that corresponds to the encoded data block corresponding to multiple uncoded data blocks.

41. The article of manufacture of claim **35**, wherein the predetermined bit pattern comprises "010", each uncoded data block comprises eight bits, and each encoded data block comprises nine bits.

42. The article of manufacture of claim **41**, wherein the first number comprises twelve and the second number comprises six.

43. The article of manufacture of claim **35**, wherein the predetermined bit pattern comprises "010", wherein each uncoded data block comprises sixteen bits and wherein each encoded data block comprises seventeen bits.

44. The article of manufacture of claim **43**, wherein the first number comprises twenty bits and the second number comprises fourteen bits.

45. The article of manufacture of claim **43**, wherein a correspondence of uncoded to encoded data blocks comprises a finite state code scheme.

46. The article of manufacture of claim **35**, wherein the predetermined bit pattern comprises "111", wherein each uncoded data block comprises nine bits and wherein each encoded data block comprises ten bits.

47. The article of manufacture of claim **46**, wherein the first number is fourteen.

48. The article of manufacture of claim **35**, wherein the predetermined bit pattern comprises "111", wherein each uncoded data block comprises sixteen bits, and wherein each encoded data block comprises seventeen bits.

49. The article of manufacture of claim **48**, wherein the first number is twenty-one.

50. The article of manufacture of claim **48**, wherein a correspondence of uncoded to encoded data blocks comprises a finite state code scheme.

51. The article of manufacture of claim **35**, wherein the predetermined bit pattern comprises either "0100" or "0010", wherein each uncoded data block comprises nine bits and wherein each encoded data block comprises ten bits.

52. The article of manufacture of claim **51**, wherein the first number is twelve.

53. The article of manufacture of claim **35**, wherein the predetermined bit pattern comprises either "0100" or "0010", wherein each uncoded data block comprises sixteen bits.

54. The article of manufacture of claim **53**, wherein each encoded data block comprises seventeen bits and wherein the first number comprises nineteen bits.

55. The article of manufacture of claim **53**, wherein a correspondence of uncoded to encoded data blocks comprises a finite state code scheme and wherein the first number is fifteen.

56. The article of manufacture of claim **35**, wherein the predetermined bit pattern is included in one encoded data block or spans two encoded data blocks.

57. An article of manufacture including code for storing input groups of uncoded binary data on a storage medium, wherein the code is capable of causing operations comprising:

receiving a plurality of uncoded data blocks in a data stream;

generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" occur within a second number of bits, wherein the first number is greater than the second number; and

storing the encoded data steam on the storage medium.

58. An article of manufacture including code for storing input groups of uncoded binary data on a storage medium, wherein the code is capable of causing operations comprising:

receiving a plurality of uncoded data blocks in a data stream;

generating one corresponding encoded data block for each uncoded data block, wherein an encoded data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" occur within a second number of bits; and

storing the encoded data stream on the storage medium, wherein the encoded data block can be used in partial response and extended partial response systems.

59. A system for storing input groups of uncoded binary data on a storage medium, comprising:

means for receiving a plurality of uncoded data blocks in a data stream;

means for generating one corresponding encoded data block for each uncoded data block, wherein an encoded

data stream obtained from concatenating successive encoded blocks includes a predetermined bit pattern comprising a plurality of bits, wherein the bit pattern always occurs within a first number of bits and two occurrences of a "1" and "0" occur within a second number of bits; and

means for storing the encoded data stream on the storage medium, wherein the encoded data block can be used in partial response and extended partial response systems.

* * * * *